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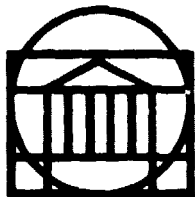
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RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES



SCHOOL OF ENGINEERING AND APPLIED SCIENCE

UNIVERSITY OF VIRGINIA

Charlottesville, Virginia 22901

A Final Report

DEMAND MODELLING OF PASSENGER AIR TRAVEL

An Analysis and Extension

VOLUME I
Background and Summary

Submitted to:

NASA Scientific and Technical Information Facility
P. O. Box 8757
Baltimore/Washington International Airport
Baltimore, Maryland 21240

Submitted by:

I. D. Jacobson
Associate Professor

Report No. UVA/528148/MAE78/101

August 1978



RESEARCH LABORATORIES FOR THE ENGINEERING SCIENCES

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INTRODUCTION

Engineers and planners in transportation have become more aware recently of the changing and searching questions that they are required to answer whenever forecasting is involved. The history of travel forecasting has been one of successively more comprehensive attempts to move from models that simply project demand to those that provide a coherent representation and organization of the complex of consumer attitudes, behavior and perceptions of service attributes that produce travel demand. The structure of such models should, in theory, permit them to respond to significant changes in the transportation service variables specified regardless of whether the level of service associated with a specific model has been experienced previously. However, this is seldom achieved with the present state-of-the-art.

The purpose of this study is to develop the framework for a model of travel demand which will be useful in predicting the total market for air travel between two cities. The goal is to identify a set of variables which can be used in a predictive way to determine the need for air transportation where none currently exists and the effect of changes in system characteristics on attracting latent demand. An investigation of existing models is carried out in order to provide insight into their strong points and shortcomings. Much of the existing behavioral research in travel demand is incorporated to allow the inclusion of non-economic factors, such as convenience. The type of model arrived at is characterized as a market segmentation model. This is a consequence of the strengths of disaggregation and its natural

evolution to a usable aggregate formulation. The need for this approach both pedagogically and mathematically is discussed below.

This report is divided into two volumes. The first gives the background and summary of the salient features leading to and including the proposed model while Volume II gives the analytic details of the data used to reach these conclusions.

SECTION I

BACKGROUND

Demand models are of many different types, and are used to forecast different aspects of future travel. There have been many applications of these models to the air mode from forecasting airport use to forecasting future travel demand between particular city pairs. Most early models are of the aggregate type - that is, they lump demand for a particular area or zone. The simplest of these types of models is a forecasting model based on historical use patterns. These do not allow the assessment of changes in system characteristics or socioeconomic pressures. The entire population of an area is lumped into a single historical pattern.

A second type is usually referred to as an economic model. It is one where the disparity between modes is, in general, linked to costs, time and distance. Some economic properties of an area (for example, per capita income) are sometimes included.

These types of models constituted the basic approach to forecasting through the mid 1960's. Since then, modeling has evolved to include abstract mode models - which try to incorporate some non-economic variables, and individual behavior models which are the basis for disaggregate modeling.

Typical of the early work in applying the abstract mode model to air transportation is the work of Howrey (1969) which is based on earlier work in the area by Quandt (1966). This type of model has been used by many authors (e.g., Crow and Longeot (1972), Cessario

(1973, 1974), Long (1970), Lave (1972) and Yu (1970)) with varying degrees of success. The independent variables in these demand models for the air transportation segment of the market vary considerably.

A significant number of demand models for air transportation of the historical, economic and abstract mode types were developed in the early 1970's for individual states as part of their state airport system planning studies (e.g., Quinton-Budling (1973), Parson (1975), Stanford Research Inst. (1974), Dalton, et. al. (1975), Oregon (1974), Foster (1972), Virginia Division of Aeronautics (1975), Aerospace Corp. (1973)). The variables used in these models fall into three groups: 1) system attributes (e.g., cost of travel, frequency of service); 2) regional attributes (e.g., population); and 3) personal attributes (e.g., income).

More recently much attention has been placed on disaggregation. Although in general disaggregation refers to any segmentation of the prediction of demand, its most common use in the literature is at the level of the individual. Examples of this type of model, which predicts the probability of an individual selecting a given mode based on behavioral variables, are given in Watson (1974) and Quarmby (1967) with an up-to-date summary given in a compendium of papers edited by Stopher and Meyburg (1976). The evolution of this technique is discussed by Quandt (1976). Most of the work in this area has been concentrated on the urban sector with very little done in intercity travel demand.

The need for market segmentation is documented in the findings of many authors (e.g., Golub, et al (1972), Golub and Dobson (1974), Nicolaides and Dobson (1975), and Jacobson and Kuhlthau (1972)). In addition, Hensher (1976) gives a lucid discussion of the mathematical need for this approach. All of these articles point to the individual behavior differences of various groups in the population and the need to account for each separately.

Perhaps the area that has received the least attention in the literature is the need for relatively invariant behavior of the models if they are to be used for forecasting; and the need for the variables to be readily forecastable. That is, a model which perfectly represents the data for the year 1978, for example, is not useful as a forecasting tool if it will not also represent the data for the year 1985; and, if the independent variables cannot be predicted for the future years.

Some general comments are useful by way of background on aggregate versus disaggregate modeling. Aggregate models suffer from several major drawbacks:

- 1) Many factors are usually omitted from aggregate models. Instead of being explicitly included, such factors are implicitly considered to be in the calibration constants. Comfort, convenience, and reliability are typical factors which are usually omitted;

- 2) Differences among types of travelers (e.g., business or pleasure) and types of cities (e.g., marketing, industrial, government, etc.) are not considered in aggregate models. Such differences are important factors, as certain groups of people use air travel heavily

(e.g., businessmen) while others do not, and certain types of cities generate more air traffic than other types of cities of similar population size.

3) The variables most commonly used in aggregate models are not of equal importance to each air travel group. For example, price is a much more important factor to the pleasure traveler than it is to the business traveler. A change in airfare will have much greater effect upon air travel demand for pleasure purposes than it will for business purposes.

4) The models do not allow for the effect of changes in service characteristics - or changes in competitive modes.

Disaggregate modeling, while providing the means for overcoming the aggregate modeling problems mentioned above, have shown shortcomings of their own:

1) Measurement of certain independent variables is difficult due to lack of agreement among proponents of models concerning what the variable should actually describe. The measurement of convenience is an example of this problem; how does one measure convenience? (Quandt and Baum, 1970).

2) Values of variable elasticities change greatly depending upon the year for which data were collected. (Yu, 1970).

It is clear that aggregate modeling is not a sufficiently powerful tool for accurately forecasting demand for air travel. Disaggregate modeling promises to be a better technique, but it is still in need of further refinement.

A more detailed review of demand modeling techniques is given in Volume II.

SECTION II

TESTS OF CURRENT AIR TRAVEL DEMAND MODELS

Several existing models used in forecasting air travel demand and formulated in the period 1970 to 1975 have been evaluated to determine the capability of these models for predicting future conditions. Each model was tested with data from a future year relative to the year in which it was calibrated. Actual data for the independent variables were compiled for the year 1974. The models were then used to calculate predicted demand, and this predicted demand was compared with the actual data for 1974. Direct comparisons can be made between predicted and actual demand, giving an indication of the capability of each model. 1974 was selected as the test year since it was the latest year for which all necessary data were available. Three states were selected for the evaluation; Virginia, Oregon and Michigan. These states were selected since models developed specifically for them had significantly different approaches and they represented different geographic regions.

Virginia State Model

1. Form of the Model

The first model to be tested was the model developed for the Virginia Air Transportation System Study. (Systems Analysis & Research Corp., 1974 and Va. Div. of Aero. 1975). This model is an economic, aggregate type used to forecast enplanements at an airport based upon system and regional attributes. The model is written as

$$\ln \frac{E'_1}{P_1} = 0.108444 - .172007F + 1.41311 \ln Y_1 \quad (1)$$

where E'_1 = predicted potential for enplanements at airport i.

P_1 = population of airport i service area

F = U. S. average airfare/mile (¢/mile, 1967 dollars)

Y_1 = per capita income of airport i service area (1967 \$)

Eq. (1) was developed by finding the system and regional attributes which most significantly correlated with trends in air activity, and by using regression analysis to determine the final form of the equation and the coefficients.

Note that this equation predicts a "potential" for enplanements; that is, the demand which would exist if the independent variables are the only ones which affect the number of enplanements. However, other factors not explicitly presented in Eq. (1) have an effect, and they are accounted for by use of a correction factor β_1 , as shown below:

$$E_1 = \beta_1 E'_1 \quad (2)$$

where E_1 = predicted enplanements at airport i.

β_1 = correction factor for airport i.

E'_1 = predicted potential for enplanements at airport i.

In the Virginia Air Transportation System Study, β_1 for each Virginia airport was determined in the following manner: (1) Eq. (1) was used to predict potential enplanements at each Virginia airport for the year for the year 1970; (2) actual enplanements for each

Virginia airport for 1970 were found; and (3) the value of β_1 for each airport was determined as the ratio of actual 1970 enplanements to predicted potential for enplanements for 1970. This value of β_1 was then considered to remain constant for future years.

2. Data Analysis

Verification of this model was undertaken using data from three states - Virginia, Michigan and Oregon. The results are presented in Vol. II.

For Virginia, all airports except Roanoke showed errors which were positive; that is, the predicted enplanements were greater than the actual enplanements. For Michigan and Oregon, the opposite situation occurred; 17 of 19 Michigan airports and 8 of 9 Oregon airports had negative errors; that is, predicted enplanements were less than the actual enplanements. Errors were small for large airports (e.g., Norfolk, +5%; Detroit, -4%; Portland, -1%). However, errors for small airports (under 100,000 in actual enplanements) were wide in range, approaching 100% in some cases.

3. Sources of Error

A large source for these errors can be attributed to the calculation of the correction factor β_1 for each airport. The value of β_1 for each airport was determined as the ratio of actual 1970 enplanements to the predicted potential enplanements for 1970. It was assumed that this value of β_1 would remain constant for the years beyond 1970. Better results could be obtained by using an historical trend.

Aside from the problem of calculating the correction factor β_1 , the Virginia Air Transportation System Study Model performed well when real data for the independent variables were used in this verification test. However, the ability to accurately forecast the independent variables is necessary in order for the model to be used as a forecasting tool.

The authors of the Virginia Air Transportation System Study Model made projections concerning future values of the Consumer Price Index and Real U. S. Average Airfare per Mile. The Real U. S. Average Airfare per Mile is one of the independent variables of this model, and the Consumer Price Index is used in computing this Airfare variable, and also the Real Per Capital Income variable (Y_1), in terms of 1967 dollar values. Neither of these variables can be forecasted with reasonable certainty.

Washington State Plan Model

1. Form of the Model

The second model to be evaluated was the Washington State Airport System Plan Model, (Aerospace Corp., 1973). It is a historical share of the market model, and is given by

$$E_i = M_{i/j} M_j / S^M_{S/U.S.} E_{U.S.} \quad (3)$$

where E_i = predicted enplanements at airport i.

$M_{i/j}$ = percentage market share for airport i of the total scheduled domestic enplanements of region j in which airport i is located.

$N_{j/S}$ = percentage market share for region j of the total scheduled domestic enplanements of state S.

$N_{S/U.S.}$ = percentage market share for state S of the total scheduled domestic enplanements in the United States.

$E_{U.S.}$ = total scheduled domestic enplanements in the United States.

2. Data Analysis

The market shares were developed for the state of Washington in the following manner: (1) the Washington State percentage of the total U. S. enplanements was calculated for the years 1962-1970. Seattle/Tacoma International Airport enplanements were excluded. Seattle is the dominant airport in the state, and fluctuations in enplanements at Seattle due to military travel and employment changes in the Puget Sound area produced large fluctuations in the data. A historical trend of Washington State's (minus Seattle) percentage of total U. S. enplanements was plotted, and a constant percentage was forecast for fiscal year 1977 and beyond; (2) Washington was divided into three regions, associated with Rand McNally Major Trading Areas.

Verification of the Washington State System Airport Plan Model was conducted by testing the model in three states: Washington, Virginia and Oregon, using actual 1974 enplanement figures for total U.S. enplanements.

3. Sources of Error

The market share model is a good forecasting tool only for airports which have a large market share of the state total. It is very difficult to make accurate forecasts for small airports. A further

drawback is the need to obtain historical data in order to develop the market share percentage, which makes this technique unusable for predicting enplanements at a new airport where no historical data exist.

Michigan State Plan Model

1. Form of the Model

The Michigan State Airport System Plan Model (SRI, 1974) was the last of the state plan models to be tested. Total travel between two regions and travel by each mode between two regions were the quantities which this model was designed to calculate. A travel "conductance" for each mode was defined as follows:

$$w_m = a_m t_m^{\alpha_m(1)} c_m^{\alpha_m(2)} \{1 - \exp(-.12 f_m)\}^{\alpha_m(3)} \quad (4)$$

where w_m = travel conductance for mode m between region i and region j .

t_m = travel time between region i and region j by mode m .

c_m = cost of travel between region i and region j by mode m .

f_m = frequency of service between region i and region j by mode m .

$a_m, \alpha_m(1), \alpha_m(2), \alpha_m(3)$ = mode-specific calibration parameters.

A total travel "conductance" is defined as:

$$W = \sum_m w_m \quad (5)$$

where W = total travel conductance between region i and region j .

w_m = travel conductance for mode m between region i and region j .

Next, the total predicted passenger travel between two regions, i and j , can be expressed by the following equation:

$$T_{ij} = \beta_i \beta_j P_i P_j W^{0.9} \quad (6)$$

where T_{ij} = predicted total travel between region i and region j.

$\beta_i \beta_j$ = regional constants for region i and region j, respectively.

P_i, P_j = populations of region i and region j, respectively.

P_i, P_j = populations of region i and region j, respectively

W = total travel conductance between region i and region j.

Travel between two regions for a single mode is thus defined as

$$T_{mij} = \frac{w_m}{W} T_{ij} \quad (7)$$

where T_{mij} = predicted travel by mode m between region i and region j.

w_m = travel conductance for mode m between region i and region j.

W = total travel conductance between region i and region j.

Substituting the expression for T_{ij} of Equation (6) into Eq. (7)

yields the following equation for travel by mode m between two regions:

$$T_{mij} = \frac{w_m}{W} \beta_i \beta_j P_i P_j W^{0.9} \quad (8)$$

As air is the mode of interest, a working equation for calculations can be achieved by substituting the expressions for w_m (Eq. (6)) and W (Eq. (7)) into Eq. (8):

$$T_{air\ ij} = \frac{\frac{a_{air} t_{air}^{\alpha_{air}(1)} c_{air}^{\alpha_{air}(2)}}{\alpha_m(1) \alpha_m(2)} \{1 - \exp(-.12 f_{air})\}^{\alpha_{air}(3)}}{\left\{ \sum \frac{a_m t_m^{\alpha_m(1)} c_m^{\alpha_m(2)}}{\alpha_m(1) \alpha_m(2)} \{1 - \exp(-.12 f_m)\}^{\alpha_m(3)} \right\}^{.1}} \beta_i \beta_j P_i P_j \quad (9)$$

The values for the mode specific calibration parameters, as presented in the Michigan State Airport System Plan, are shown in Table 1.

TABLE I

Values of Mode Specific Calibration Parameters

<u>Mode</u>	<u>a_m</u>	<u>$\alpha_m(1)$</u>	<u>$\alpha_m(2)$</u>	<u>$\alpha_m(3)$</u>
Auto	13.76	- 1.6	- 1.6	0
Bus	1.50	- 1.5	- 1.5	0.3247
Air (except Chicago-Detroit)	1.50	- 1.5	- 1.5	0.3247
Air (Chicago-Detroit only)	0.75	- 1.5	- 1.5	0.3247

2. Data Analysis

The state of Michigan was divided into 27 regions. Some regions did not have their own airports, and were dependent upon a neighboring region for air service. The continental United States outside of Michigan was divided into 29 regions. The external regions surrounding Michigan were small in land area, constituting only parts of neighboring states. As distance away from Michigan increased, regions increased in size, constituting groups of states.

Each region, both within and outside Michigan was given a regional constant and a "gateway" city was selected as the representative city of the entire region for the purpose of calculation.

3. Sources of Error

In general the predictions are much too low, however, the study of travel between city pairs yields insight into travel patterns of a community. The major difficulty encountered is probably due to the need for increasing size regions as the distance from the origin city increases. This dilutes the ability to determine the real destination demands and may make the prediction with a given city erroneous if it does not reflect the true travel to the region.

SECTION III

DEVELOPMENT OF A NEW AIR DEMAND MODEL

The results of the tests performed on present air demand models shows the need for more sophisticated modeling techniques in order to achieve an accurate forecasting tool. From a study of the literature, it is apparent that the travel habits of different groups of people differ. Considerable research has been done in an attempt to find the most important factors which influence air travel (e.g., Kuhlthau and Jacobson, 1976, Jacobson and Kuhlthau, 1972, Lee and Jacobson, 1972, Port of N. Y. Authority, 1957 and Federal Aviation Agency, 1963). A comparison of the factors used in several studies is given in Table 2. From these and other references a list of the factors considered to be most important are presented in Table 3. Also, it has been shown that the traveling public can be divided into distinct groups according to the purpose of the trip, (Yu, 1970, Lee and Jacobson, 1972, Port of N.Y. Authority, 1957). Different factors influence the travel decision process according to the purpose of the trip; therefore, a new air demand model should segment air demand due to business travel and air demand due to pleasure travel. Several other market segmentations may also be necessary.

From a purely mathematical viewpoint using nonsegmented data can lead to incorrect assumptions when doing regression analyses. This has been discussed by Hensher (Hensher, 1976) who pointed out the difficulties which can be encountered. For example, consider the variation in number of trips generated between city i and city j with

income. Consider two groups - those with high education and those with low education levels. The data might well be distributed as shown in Figure 1. The actual behavior with income variation as predicted by linear regression would not accurately represent the true travel behavior. If the market were segmented by education level then true behavior would be represented.

It is felt that the major shortcomings of past aggregate models has been their inability to segment the data properly. The natural end point for this segmentation is behavior on an individual level - what is commonly referred to as disaggregate modeling. For inter-city travel - as opposed to intracity travel - the ability to use market segmentation to disaggregate the data offers a useful alternative to the extreme of individual behavior. It has some of the same advantages of the treatment of individual data - e.g., requires less information for modeling since only a limited number of data points is needed in each cell (segmentation). And, it does not suffer from the drawbacks of complete aggregation - e.g., nonlinear effects lost in data pooling. In a study by Nicolaidis and Dobson (1975) it was shown that no individual is distinct but shares common preference patterns. This commonality forms the basis for segmentation.

Two of the three models investigated - the Virginia and Washington State Plan Models - were designed only to forecast total enplanements from a region. These models lacked the capability to determine the demand from the region under study to particular destination regions. The Michigan State Plan Model did provide the methodology necessary

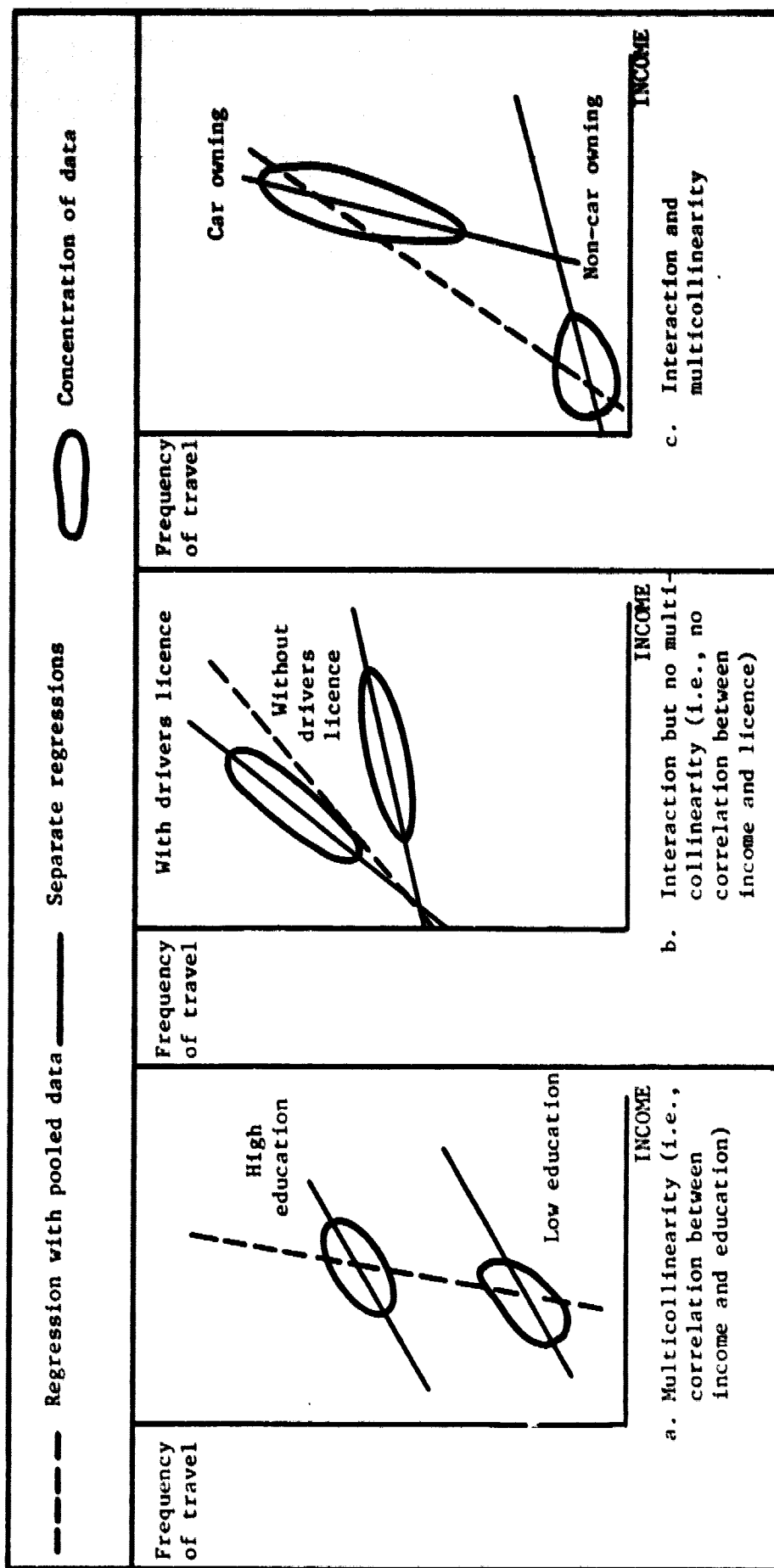


Figure 1 Interaction and Intercorrelation (from Hensher, 1976)

TABLE 2

Variable \ Author	Billheimer	Goodknight	Judycki, et al.	Kanafani & Fan	Kraft & Kraft	Navin & Wolsfeld	Su	Yu	Jacobson & Kuhlthau	FAA
Time	X		X	X	X			X	X	
Cost	X			X	X			X	X	
Departures/day	X			X				X	X	
Attractiveness		X						X		
Taxable Payroll		X								
Population		X		X			X	X		
Hotel & Motel Payroll		X								
No. of Registered Autos			X					X		
Income			X	X		X	X			
Demand Deposits			X					X		
No. of College Students			X					X		
Employment in Gov't.			X			X				X
Comfort					X				X	
Convenience					X		X		X	
No. of hotel/motel rooms						X				
Emp. in Wholesal/Man.						X		X		X
Emp. in Finance/Ins./Real Estate						X				X
Emp. in Retail						X				X
No. of dwelling units						X				
Distance							X			
Property Value								X		
Sales Tax								X		
Safety									X	
Reliability									X	
Abil. to Work									X	

TABLE 3

List of Factors Considered Important to Air Travel Demand

MODE VARIABLES

Comfort
Convenience
Cost
Reliability
Safety
Service
Speed

PERSONAL VARIABLES

Age
Education
Income
Occupation
Car Ownership

REGIONAL VARIABLES

Employment
Industrial Characteristics
Population

TRIP VARIABLES

Length of Stay
Number of persons
traveling in party
Number of stops in
travel itinerary
Purpose of trip
Travel time (or
distance)

to study demand between particular regions, thus providing a greater understanding into the nature of the demand. A new air demand model should investigate the demand between pairs of regions, and the total demand for air travel in a particular region can be simply calculated by summing the demands from that region to all destination regions.

Form of Proposed Models

The following equations are proposed which will segment the demand. At the minimum, segmentation should be by purpose of trip. Here air demand for business is proposed to be the following:

$$T_{ijb} = f_{lb}(t,d) \frac{P_i^{\alpha_1} P_j^{\alpha_2}}{D_{ij}^{\alpha_3}} Ch_i^{\alpha_4} Ch_j^{\alpha_5} \{g_{1b} T_{ij} E_{ijb}^{\alpha_6} + g_{2b} W_{ij} c_{ij}^{\alpha_7}\} R_{ij}^{\alpha_8 \alpha_9 \alpha_{10}} \quad (10)$$

where T_{ijb} = number of air travelers from region i to region j for business purposes

$f_{lb}(t,d)$ = function of length of stay in region j and distance between regions i and j.

P_i, P_j = populations of regions i and j, respectively.

D_{ij} = distance from region i to region j

Ch_i, Ch_j = industrial characteristics of regions i and j, respectively.

g_{1b} = function of air mode system characteristics

T_{ij} = travel time from region i to region j by air mode

E_{ijb} = convenience of air mode from region i to region j (e.g., scheduling, number of seats available during peak travel hours, ease of airport access and egress)

g_{2b} = function of air mode comfort characteristics (e.g., seat comfort, ride quality, etc.)

W_{ij} = ability to work while traveling (space to work, ability to read and write, etc.)

C_{ij} = comfort characteristics (e.g., seat comfort, ride quality, etc.)

R_{ij} = road conditions between i and j

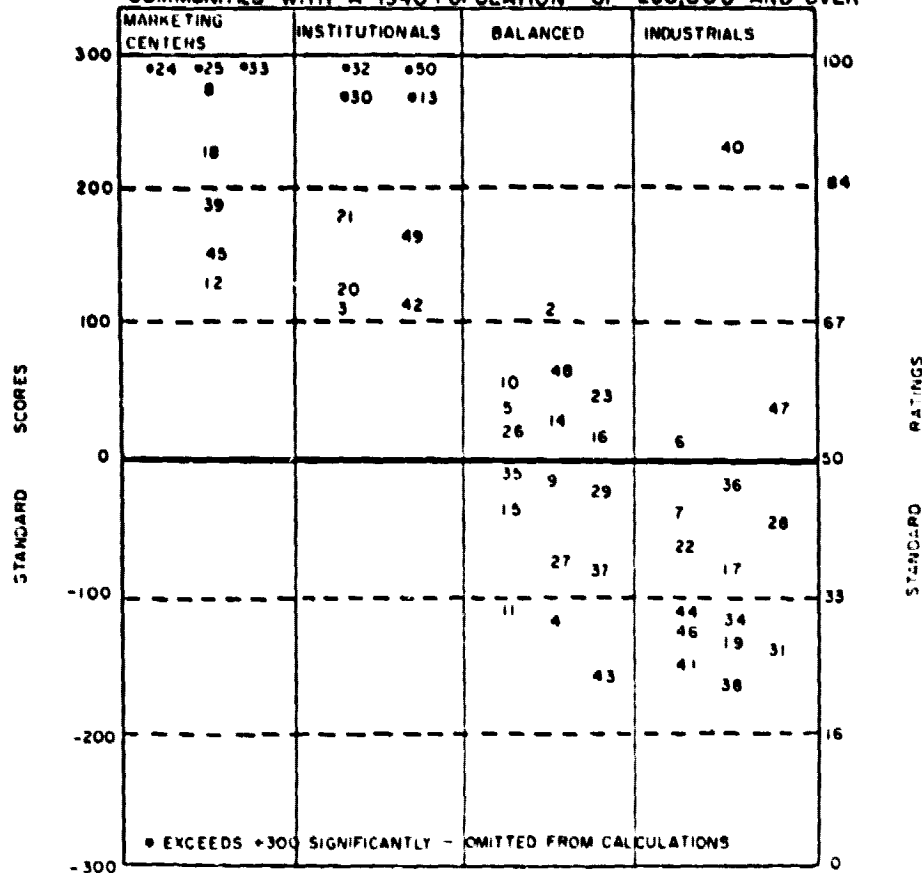
Notice Eq. (10) contains a term which is the product of the two regional populations divided by the distance between them; such a term is called a "gravity" term because of its similarity to the equation describing the gravitational attraction of two physical objects. The gravity term is considered the basis of attraction between the two regions i and j, and therefore the basis of travel between them. It is modified by the industrial characteristics of the regions to account for the fact that certain industries have greater travel needs than others (Port of NY Authority, 1967, Federal Aviation Agency, 1963). Regions are classified according to the type of businesses which are the most important. For example, an FAA study of business characteristics of metropolitan areas, classified each area in one of four categories: (1) marketing center; (2) institutional (e.g., government or academic); (3) industrial (e.g., manufacturing); (4) balanced, i.e., none of the three types were dominant. The general findings of this study were that marketing centers and institutional center were heavy users of air travel, while industrial centers were low users by comparison, and balanced cities were average users (Figure 2). Thus,

Figure 2

ENPLANED AIRLINE PASSENGERS PER 10,000 POPULATION

JULY - SEPTEMBER 1947

COMMUNITIES WITH A 1940 POPULATION OF 250,000 AND OVER



METROPOLITAN DISTRICT KEY							
NO	NAME	NO	NAME	NO	NAME	NO	NAME
1	NEW YORK	14	BUFFALO	26	LOUISVILLE	39	MEMPHIS
2	CHICAGO	15	MILWAUKEE	27	ALBANY SCHENECTADY	40	NORFOLK PORTSMOUTH
3	LOS ANGELES	16	CINCINNATI	28	HOLMESTER NY	41	LENTOWN-BETHLEHEM
4	PHILADELPHIA	17	PROVIDENCE	29	BIRMINGHAM	42	SAN ANTONIO
5	BOSTON	18	KANSAS CITY	30	PORTLAND	43	NEW HAVEN
6	DETROIT	19	SCHANTON	31	SPRINGFIELD-HOLYOKE	44	WORCESTER
7	PITTSBURGH	20	NEW ORLEANS	32	DENVER	45	OMAHA
8	SAN FRANCISCO	21	HOUSTON	33	DALLAS	46	FALL RIVER
9	ST. LOUIS	22	HARTFORD	34	YOUNGSTOWN	47	DAYTON
10	CLEVELAND	23	INDIANAPOLIS	35	COLUMBUS OHIO	48	SYRACUSE
11	BALTIMORE	24	SEATTLE	36	AKRON	49	SAN DIEGO
12	MINNEAPOLIS	25	ATLANTA	37	TOLEDO	50	MIAMI
13	WASHINGTON, D.C.			38	LOWELL-LAWRENCE		

The Standard score, obtained by dividing the deviation from the mean by the standard deviation in any one series (e.g. 1) is a useful statistical device for measuring the position of an item and comparing it with all other items. Standard scores can be converted to numerical ratings. For example, in a score rating in which 50 is the average, the standard score is divided by 4 (approx.) and the resulting figures subtracted or added to 50 depending on whether the standard score is minus or plus.

given two regions of the same population size, a marketing center would enplane more passengers than a manufacturing (industrial) center. The industrial characteristics variables in Eq. (10) act as modifiers of the population variables.

The function $f_{1b}(t,d)$ is another modifier of the gravity term. This function represents the personal decision making process to use air rather than another mode, based upon the distance of the trip and the length of stay at the destination. For example, a 300-mile trip for a day clearly necessitates the use of air, whereas a trip of 300 miles for a week's duration may be more practical by auto (especially if an auto would be needed at the destination during the weeklong stay). Generically this function might appear as shown in Figure 3.

The remaining terms in Eq. (10) can be considered system attributes which modify the basic personal and regional demands for air travel. Total travel time by air and convenience of the air mode represent the two most important system attributes, and could be considered "air advantage" variables; that is, would reflect the superiority (or inferiority) of the air mode versus other available modes for the business trip. The last two variables, ability to work and comfort, represent "personal taste" of the traveler, and again reflect a potential advantage or disadvantage for the air mode compared with other modes.

Notice that some of the factors listed in Table 3 are not included in Eq. (10). In business travel decisions these factors are not

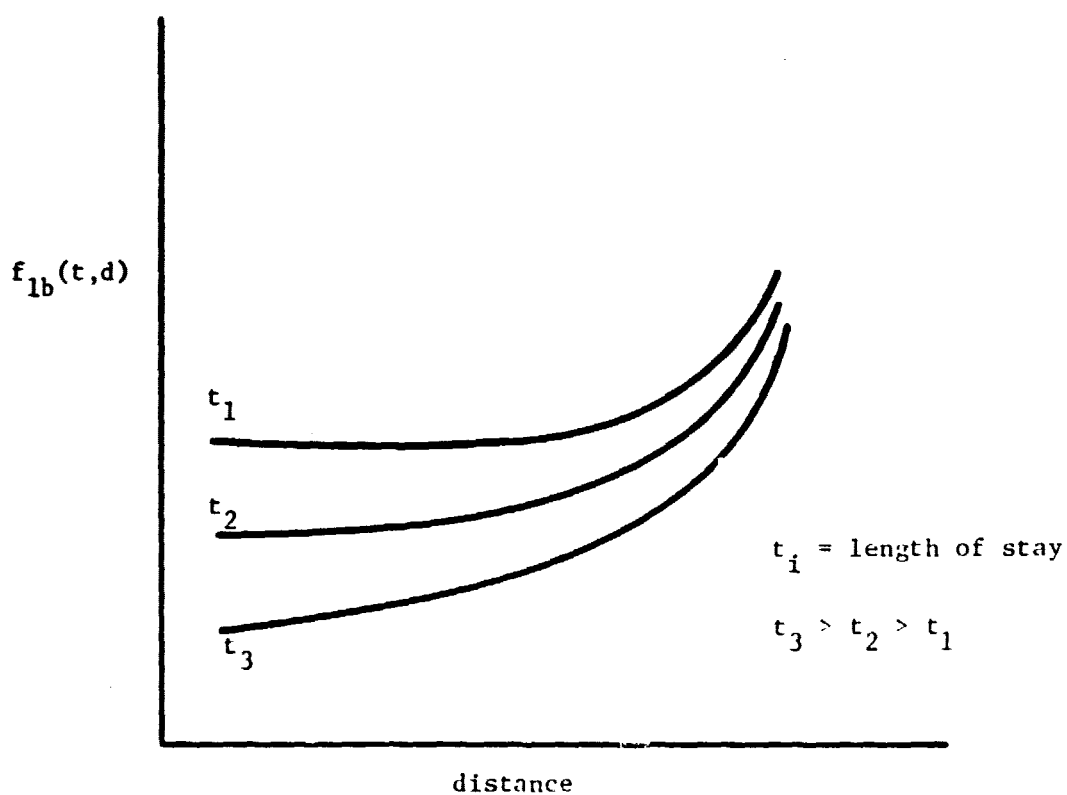


Figure 3 Conceptual Behavior of Gravity Modifier f_{1b}

considered important in the process of travel choice. Of the mode variables, comfort and convenience were used in the model, but cost, reliability, and safety were not. Cost has been found to be a relatively non-critical factor for business travelers. (Jacobson, I.D. and Kuhlthau, A. R., 1972). Reliability and safety are important, but the business traveler considers both of these to be very good for the air mode, and therefore not critical in the decision making process. Service is related to comfort and convenience, which are included in the model, and speed is related to travel time.

No personal variables were included. For business travelers, these four factors are highly interrelated, and are also related to the industrial characteristics of the region. Likewise employment can be considered as part of the regional industrial characteristics.

Of the trip variables, purpose of trip has been considered to be the most important, and has been used as the means of disaggregating the traveling public. All other trip variables are included in Eq. (10), except for the size of the traveling party, which was considered unimportant.

In the same manner that an equation for air demand for business purposes was developed, an equation for pleasure travel demand was formulated, and is shown below:

$$T_{ijp} = f_{lp}(t, d, p, s) \frac{P_i^{B_1} P_j^{B_2}}{D_{ij}^{B_3}} I_i^{B_4} A_j^{B_5} R_{ij}^{B_6} \{ g_{1p} S_{ij}^{B_6} T_{ij}^{B_7} E_{ijp}^{B_8} + g_{2p} R_{ij}^{B_9} S_{ij}^{B_{10}} \} \quad (11)$$

where T_{ijp} = number of air travelers from region i to region j , for pleasure purposes

$f_{ip}(t,d,p,s)$ = function of length of stay in region j , distance between regions i and j , number of people in the party, and number of stops (other secondary destinations), in itinerary.

P_i, P_j = populations of region i and j , respectively

D_{ij} = distance from region i and region j

I_i = income distribution in region i .

A_j = attractiveness of region j .

R_{ij} = road conditions between i and j

g_{1p} = function of air mode system characteristics

S_{ij} = cost of air travel from region i to region j .

T_{ij} = travel time from region i to region j by air mode.

E_{ijp} = convenience of air mode from region i to region j
(different from convenience as perceived by business traveler)

g_{2p} = function of air mode dependability characteristics as perceived by pleasure travelers

R_{ij} = reliability of air mode (e.g., on-time performance)

S_{ij} = safety of air mode as perceived by pleasure travelers

Eq. (11) is similar in form to Eq. (10). Once again, the gravity term is the basis for the attraction between the two regions. Instead of industrial characteristics of the two regions, the income distribution of region i and the attractiveness of region j are the modifiers used. Regions of high attractive value would be places which attract a large number of tourists (e.g., Florida, California, etc.).

As with business travelers, the length of stay and distance would play a role in the decision making process, and also the number of people traveling together (i.e., individual, adult couple, entire family, etc.), and the number of places planned to be visited enroute (e.g., a vacation trip in which it is desired to visit all attractive regions in Florida or California, etc.), would come into consideration. See Figure 4 and 5.

As for the mode variables, travel time and convenience are included, although "convenience" for a pleasure traveler is probably different than for a businessman. For example, a pleasure traveler would be interested in a flight which would have discount seats, whereas a businessman would be concerned with finding a flight which best matches his business itinerary. Cost is a very important factor in pleasure travel, and safety and reliability also play an important part in decision making. Fear of flying is still a strong negative factor among a sizeable fraction of the traveling public, and is probably strongest among people who have never used air travel. Although this is probably due to a lack of familiarity with air travel, it is still a problem that needs to be overcome before air travel becomes a serious contender in planning a pleasure trip.

Combined Model

Although the above models represent a conceptual approach to the problem it is important to note that not all of the variables can be easily obtained. For the purpose of this study it was felt that some non-conventional variables should be tested to ascertain their ability

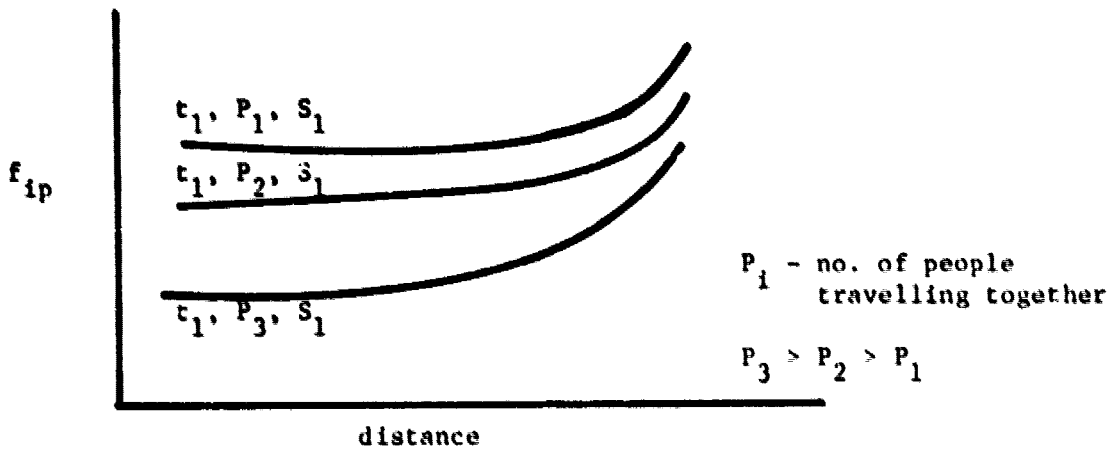


Figure 4. Conceptual Behavior of Gravity Modifier f_{ip} as a Function of Number of People Travelling Together i_p

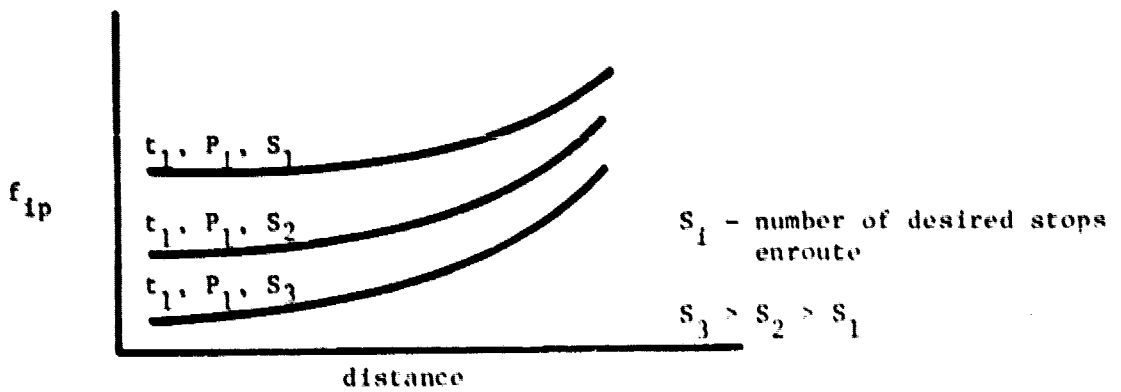


Figure 5 Conceptual Behavior of Gravity Modifier f_{ip} as a Function of Number of Desired Stops Enroute

to model the demand. To this end a subset of the above variables was chosen for analysis. These included:

- o population city i, P_i
- o population city j, P_j
- o distance between city i and j, D_{ij}
- o road conditions around city i to airport in city i, R_i
- o road conditions around city j to airport in city j, R_j
- o attractiveness of city i, A_i
- o attractiveness of city j, A_j
- o number of seats available, S_{ij}
- o characteristics of city i, Ch_i
- o characteristics of city j, Ch_j
- o reliability of flights, K_{ij}
- o Cost, C_{ij}
- o Time, T_{ij}

Many regression models were run using data from 251 city pairs (see Volume II). Various combinations of parameters were fixed and various forms of the model exhausted. A complete discussion of the results can be found in Volume II. Based on these a model for trips from city i to city j, where the distance is greater than 300 miles is given by

$$T_{ij} = K \frac{P_i^{.62} P_j^{.35}}{D_{ij}^{.58}} R_i^{4.88} A_j^{.03} S_{ij}^{1.25} F_{ij}^{.38} Ch_i^{-.38} Ch_j^{-1.04} \quad (12)$$

where the number of seats and number of flights are a combination of

direct flights and a reduced number depending on the connections and number of stops, and the characteristics of city i and j are the percent employed in manufacturing and wholesale and retail trade respectively. A more detailed description of these can be found in Volume II.

Several points are worth noting here. First, conspicuous by its absence is the time variable. This is due to the fact that time and distance are highly interrelated for a single mode and thus the effect of time is embedded in the distance variable. Another point to note is the negative exponents on the city characteristics. This implies that the more manufacturing (and thus less government, education, professional, etc.) the fewer trips generated in region i and the more retail trade (less gov't., education, prof. and manufacturing) the fewer trips attracted by j. In addition the population of the originating city is more of a determining factor than the population of the destination city.

This model which is significant at better than the .01 level accounts for 93% of the variance or has a correlation coefficient of $r=0.963$. It is felt that although this model is a composite model with many assumptions it has demonstrated the ability of non-conventional, more easily forecastable variables to predict demand.

SECTION IV

CONCLUSIONS

Several conclusions can be drawn from this study:

- **a more sophisticated model to predict travel demand is needed**
- **many existing variables used to predict demand cannot be forecasted reliably**
- **market segmentation is necessary to develop better demand for forecasting models**
- **non-conventional (i.e. other than cost and time) variables can be used to predict demand**
- **there is a distinct lack of data to use for non-economic demand models**

SECTION VII

REFERENCES

1. Aerospace Corporation, Technical Supplement, Washington State Airport System Plan, Seattle, November 1973.
2. Cesarão, F. J., "A Generalized Trip Dist. Model Aggregate," J. Reg. Sci., Vol. 13, No. 2, 1973.
3. Cesario, F. J., "More on the Generalized Distribution Model," J. Reg. Sci., Vol. 14, No. 3, 1974.
4. Civil Aeronautics Board, Origin-Destination Survey of Domestic Passengers, April 1, 1972 to March 31, 1973.
5. Crow, Robert and Longeot, Jean, "A Forecasting Model of the Market for New Aircraft: The Case of the Concord," Transpn. Res. Vol. 6, pp. 211-224, Pergamon Press, 1972.
6. Dalton-Dalton-Little-Newport, Ohio State System Plan, Vol. II, Technical Supplement, August 1975.
7. FAA/CAB, Airport Activity Statistics, 12 months ending December 31, 1974.
8. Federal Aviation Administration, Aviation Forecasts, Fiscal Year 1977-1988, FAA-AVP-76-17, Sept. 1976.
9. Federal Aviation Agency, Air Traffic Patterns and Community Characteristics, 1963.
10. Foster, Ralph E., "Air Passenger Demand Model: Description," Texas Airport System Plan, August 1972.
11. Golob, Thomas F., Canty, Eugene T., and Gustafson, Richard L., "An Analysis of Consumer Preferences for a Public Transportation System," Transpn. Res., Vol. 6, pp. 81-102, Pergamon Press 1972.
12. Hensher, D. A., "Market Segmentation as a Mechanism in Allowing for Variability of Traveler Behavior," Transportation, Vol. 5, 1976, pp. 257-284.
13. Howrey, E. Philip, "On the Choice of Forecasting Models for Air Travel," Journal of Regional Science, Vol. 9, No. 2, 1969.
14. Jacobson, I. D. and A. R. Kuhlthau, "Mathematical Modeling to Determine Criteria for Evaluating Human Acceptance of Transportation Systems," NASA Grant NGR 47-005-181, Department of Engineering Science and Systems, University of Virginia, August 1972.

15. Kuhlthau, A. R. and I. D. Jacobson, "Demand Modeling and Its Effect on the Design and Operation of Transport Aircraft," Proposal submitted to NASA, Department of Engineering Science and Systems, University of Virginia, May 1976.
16. Lave, Lester B., "The Demand for Intercity Passenger Transportation," Journal of Rep. Science, Vol. 12, No. 1, 1972.
17. Lee, W. and I. D. Jacobson, "Characteristics of the Air Traveler - A Selective Review," Memorandum Report 403204, Short-Haul Air Transportation Program, Department of Engineering Science and Systems, June 1972.
18. Long, Wesley H., "The Economics of Air Travel Gravity Models," Journal of Regional Science, Vol. 10, No. 3, 1970.
19. Nicolaidis, Gregory C. and Dobson, Ricardo, "Disaggregated Perceptions and Preferences in Transportation Planning," Trans. Res. Vol. 9, pp. 379-395, Pergamon Press 1975.
20. Official Airline Guide, North American Edition, July 1, 1974.
21. Oregon Transportation Commission, Oregon State System Plan, Technical Appendix B, 1974.
22. Parson, Ralph M., Co., Illinois State System Plan, March 1975.
23. Port of New York Authority, Air Travel Forecasting, 1965-1975, Eno Foundation for Highway Traffic Control, 1957.
24. Quandt, Richard E., "Tests of the Abstract Mode Model," in Studies in Travel Demand, Vol. 2, Princeton, New Jersey, Mathematics, 1966.
25. Quandt, R. E., and W. J. Baumol, "Demand for Abstract Transport Modes: Theory and Measurement," contained in The Demand for Travel: Theory and Measurement, Heath Lexington Books, 1970.
26. Quandt, Richard, "The Theory of Travel Demand," Trans. Res. Vol. 31, pp. 411-413, Pergamon Press 1976.
27. Quarmby, D. A., "Choice of Travel Mode for the Journey to Work: Some Findings," Journal of Transport Economics and Policy, 1 (1967).
28. Quinton-Budlong, "Forecasting and Methodology, Report" Vol. 2, Florida Aviation System Plan, Los Angeles, California, February 1973.
29. SPSS, Statistical Package for the Social Sciences, User Manual, 1976.
30. Stanford Research Institute, Technical Report, Michigan State Airport System Plan, 1974.

31. Stopher, Peter R. and Mayburg, Arnim H., Behavioral Travel-Demand Models, Lexington Books, D. C. Heath and Company, Lexington, Massachusetts 1976.
32. Virginia Division of Aeronautics, Virginia Air Transportation System Study Phase III, Working Paper on Air Carrier Passengers, Cargo, and Mail Forecasts, April 1974.
33. Virginia Division of Aeronautics, and Howard, Needles, Tammen and Bergendoff, The Virginia Air Transportation System Study, Technical Supplement, Volume II, Part 2, Final Draft, 1975.
34. Watson, Peter L., "Homogeneity of Models of Transport Mode Choice: The Dimensions of Trip Length and Journey Purpose," Journal of Regional Science, Vol. 14, No. 2, 1974.
35. Yu, J. C., "Demand Model for Multimode Travel," Transportation Engineering Journal, May 1970.
36. Su, V. and Huffman, L., "Demand for Air Travel Between New York City and Other Large Cities," TRR529 Air Travel and Aviation Facilities Planning, 1975, pp. 10-16.
37. Yu, J. C., "STOL Passenger Demand in Underdeveloped Areas," Transp. Engr. J., August 1971, pp. 475-90.
38. Billheimer, J. W., "Segmented, Multimodel, Intercity Passenger Demand Model," HRR392, Transportation Demand and Analyses Techniques, 1972, pp. 47-57.
39. Judycki, D. C., Wegmann, F. J. and Carter, E. C., "West Virginia Commercial Air Trip Generations," Transportation Engr. J., Vol. 96, No. TE2, May 1970, pp. 185-201.
40. Kanafani, A. K. and Fan, S. L., "Estimating the Demand for Short-Haul Air Transport Systems," TRR526, Travel Demand Forecasting, 1974, pp. 1-15.
41. Kraft, J. and Kraft, A., "Mode Choice Characteristics as Determinants of Interurban Transport Demand," Transp. Res., Vol. 10, pp. 31-35, 1976.
42. Navin, F. P. D. and Wolsfled, R. P., Jr., "Analysis of Air Passenger Travel in the Twin Cities Metropolitan Area," HRR369, Choice of Travel Mode Considerations in Travel Forecasting, 1971, pp. 26-38.